SYNOPSIS OF RESEARCH PROJECT

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8.	**Title of Research Project**	**:**	**DEVELOPMENT AND PERFORMANCE EVALUATION OF PNEUMATIC SELECTIVE COTTON PICKER**

9. Introduction

Cotton (*Gossypium spp*.) is widely recognized as the “king of fibres” and often referred to as “white gold” due to its significant economic importance. As a globally significant commodity, this cash crop is farmed extensively in over 100 nations (Gupta *et al*., 2017). India holds the leading position in terms of area under cotton cultivation, covering approximately 11.2-11.5 million hectares during 2024-25. In terms of production, India continues to be one of the leading producers globally, with an estimated output of around 29-30 million bales in the 2024-25 season, although slight fluctuations have been observed due to variations in yield and climatic conditions. The average productivity of cotton in India has shown modest improvement, reaching approximately 447-476 kg per hectare in recent years, which remains close to but still below the global average (USDA Foreign Agricultural Service, 2025). Among the cultivated species, *Gossypium hirsutum* L. is the most predominant and economically important fibre crop both globally and within India.

Cultivated from the genus *Gossypium*, cotton is a soft, staple fiber that matures within protective bolls around the plant's seeds. While it remains the dominant natural

fiber within the global textile sector, its economic and industrial significance extends far beyond fabric manufacturing. The crop functions as a versatile raw material, contributing to the production of high-quality vegetable oils and providing nutrient-dense livestock feed through processed meal and hulls. Additionally, its unique chemical properties make it an essential component in various pharmaceutical and industrial applications. Additionally, cotton by-products are utilized as energy sources, soil-enhancing organic matter and industrial lubricants, highlighting its multifaceted role in agriculture and industry.

Estimates from the International Cotton Advisory Committee (ICAC), suggested that the global cotton production for the 2024-25 season is projected to reach between 25.5 and 26.0 million tonnes., showing a moderate increase compared to the previous year (Anon., 2024). India remains one of the world's leading cotton producers, ranking second after China, with production estimated at around 6.162 million tonnes (approx. 34-36 million bales of 170 kg each). Cotton is grown in three separate agro-climatic zones in India: The North zone, which includes Punjab, Haryana and Rajasthan, the Central zone, which includes Maharashtra, Gujarat and Madhya Pradesh and the South zone, which includes Tamil Nadu, Karnataka and Andhra Pradesh. Cotton cultivation is predominantly rainfed in nearly 60% of the area, while the remaining 40% being an irrigated. The geographical distribution of cotton cultivation across various Indian states, alongside their respective output volumes and yield rates, is detailed in Table 1.

Table 1. State wise cotton cultivation in India

(Anon., 2025)

(1 bales = 170 kg)

Sr.	State	Year 2024-2025		
		Area, lakh ha	Production, lakh bales	Yield, kg/ha
1	Andhra Pradesh	4.05	8.77	368
2	**Gujarat**	**23.92**	**71.34**	**507**
3	Haryana	5.78	12.44	366
4	Karnataka	6.70	19.15	486
5	Madhya Pradesh	5.37	15.35	486
6	Maharashtra	40.86	89.09	371
7	Odisha	1.47	5.17	598
8	Punjab	1.00	2.72	462

9	Rajasthan	6.27	18.45	500
10	Tamil Nadu	0.63	1.30	351
11	Telangana	18.11	49.86	468
12	Others	0.31	0.61	335
	Total	**114.47**	**294.25**	**441.5**

G.herbaceum, *G.hirsutum*, *G.arboreum* and *Intra-hirsutum* are the most common cotton species grown in India. Apart from *G.hirsutum* and *G.arboreum*, *G.herbaceum* is grown in Gujarat. So far, 7 *G.hirsutum* varieties, 4 *G.arboreum* variants and 11 *G.herbaceum* varieties have been released in this state. Two *G.hirsutum* varieties (G.Cot 12 and G.Cot 16), three *G.arboreum* varieties (Sanjay, G.Cot 15 and G.Cot 19) and three *G.herbaceum* varieties (G.Cot 13, G.Cot 17 and G.Cot 19) are now being grown. (Phundan S. and Kairon M. S., 2020).

Cotton harvesting generally requires about 170 to 200 days to complete. The crop is harvested either manually through hand picking or by using mechanical pickers. In India, manual harvesting is still the dominant practice; however, it often faces challenges such as labour shortages during peak picking periods. This shortage not only leads to delays in harvesting but also affects subsequent agricultural operations and may result in yield and quality losses. In contrast, mechanical harvesting reduces dependence on labour and ensures timely completion of the picking process.

In developed countries, mechanical cotton pickers are extensively used for harvesting. These machines are designed to selectively pick only mature, open bolls while leaving the immature and unopened ones on the plant for later harvests. On the other hand, cotton strippers operate non-selectively by removing both opened and unopened bolls simultaneously, often after chemical defoliation. Although these machines significantly improve efficiency, their adoption is limited owing to high initial investment costs. The mechanical extraction of cotton bolls is facilitated by specialized interfaces, including spindles, rollers, brushes, or fingers that detach the cotton bolls from the plant. Mechanized harvesting not only reduces human drudgery but also helps maintain timeliness, which is crucial for planning the next cropping cycle. Fully mechanized cotton harvesting is commonly practiced in countries like Australia, Israel and the United States, where operational costs and technologies vary considerably.

In India, cotton picking is predominantly carried out by human labour, making it a labor-intensive and time-consuming activity. Labor requirements represent a primary driver of the total resource commitment in cotton agronomy. The process involves repetitive movements, uncomfortable body postures and physical strain due to carrying picked cotton, as well as finger injuries caused by contact with sharp bracts. According to (Selvan *et al*., 2012), picking cotton by hand takes 1565 man-hours per hectare. Cotton is grown on both large and small farms in India. Furthermore, the small and fragmented landholdings, along with the staggered flowering pattern of cotton plants in India, the application of large-scale mechanical pickers less suitable. This leads to, selective picking remains necessary under Indian conditions. Despite the need for mechanization, research on small-scale or knapsack-type cotton pickers suitable for Indian farms has been limited.

10. Practical Utility of the Research Project

The cotton-growing area has been expanding steadily in recent years, primarily because of widespread adoption of Bt cotton varieties and the favorable market prices of cotton. Maintaining timeliness during harvesting is essential to preserve fibre quality and minimize losses. However, cotton picking is among the most labor-intensive tasks in its cultivation and farmers often face acute labour shortages during the busiest time of harvest. As a result, the cost of labour increases significantly, placing additional financial pressure on growers. To address these challenges, there is a growing need for efficient and affordable mechanical solutions for cotton harvesting. The development of such equipment can help reduce labour dependency, lower harvesting costs and improve operational efficiency. Significant initiatives have focused on the engineering of specialized equipment intended to amplify workforce efficiency and mitigate the ergonomic challenges faced by laborers. Therefore, the present study was undertaken to develop and evaluate a pneumatic selective cotton picker, aiming to provide a practical and efficient solution tailored to the needs of cotton farmers.

11. Objectives

1. To study the engineering properties of cotton boll.
2. To develop a pneumatic selective cotton picker.
3. To evaluate the performance of developed selective cotton picker.
4. To assess the economics of pneumatic selective cotton picker.

12. Review of Literature

This chapter gives a summary of the existing research related to cotton cultivation and the development of cotton picking technologies. The following section synthesizes the existing literature most pertinent to this study. The review is organized into specific sections to clearly present the different aspects associated with the research area.

1. Physical characteristics of cotton bolls
2. Cotton picker
3. Economics of cotton picker

12.1. Physical characteristics of cotton bolls

Murugesam R. and Manojkumar T. S. (1999) focused on evaluating the picking force required for different cotton varieties. For this purpose, the researchers designed and developed a specialized test setup to measure the force needed to detach cotton bolls from the plant. Five cotton varieties CNH-36, Anjali, LRA-5166, AKA-8401 and AKH-4 were examined during the study. The results indicated that the Anjali variety required the highest picking force, recorded at 3.456 N. Additionally, the average kapas weight among the tested varieties ranged between 2.31 g and 3.56 g, while the bract weight varied from 0.78 g to 1.33 g. Additionally, it was noted that the picking force differed among varieties and showed a direct relationship with kapas weight, increasing as the kapas weight increased.

Gora *et al*. (2020) focused on evaluating the physical attributes of the GTHH-49 cotton hybrid were rigorously quantified. Their analysis focused on critical morphological and mechanical properties, including boll mass, dimensions and density, as well as moisture levels and the detachment force necessary for harvesting. The results indicated that the average boll weight was 4.24 g, with the measured values falling within 3.15 g and 7.74 g. The mean diameter of the bolls was recorded as 37.03 mm, varying from 27.39 mm to 47.91 mm. Similarly, the average volume was found to be 29082.23 mm^3, with a range of 20544.16 mm^3 to 54658.77 mm^3. The density of the cotton bolls was estimated by taking the ratio of their theoretical weight to volume. The average density was calculated as 0.000147 g/mm^3, with values that rang from 0.000126 and 0.000192 g/mm^3. The moisture content of the bolls was observed to lie between 5.0% and 8.6%. Furthermore, the study reported that an average force of 3.14 N (equivalent to 320.7 g) was needed to detach a cotton boll from the plant.

12.2. Cotton picker

Ahmed (1985) conducted research on the mechanical harvesting of cotton in the US. The economic study discovered that mechanical picking was 20% more costly than hand picking. Although machine-picked cotton was of worse quality than hand-picked cotton, this difference was negligible. The number and spacing of the picking zone, the size, shape, sharpness and angle of the spindles. The mechanical parameters that had the biggest impact on the machine's performance were the spindle cleaning mechanism.

Ahmed *et al.* (1987) examined the technical and economic viability of mechanical harvesting of Acala cotton under Rahad conditions. Their study involved evaluating the performance of three different types of cotton picking machines to identify the most suitable option for the region. The findings indicated that mechanical harvesting has high fixed costs, mainly due to the expensive initial investment in machinery, the need for supporting equipment and considerable maintenance and repair expenses. The authors also emphasized that labour scarcity during the peak harvesting season is a major constraint, often making it difficult to rely solely on manual picking. They highlighted that delays in harvesting due to insufficient labour can lead to increased losses of seed cotton and deterioration in lint quality. Therefore, these factors must be carefully considered when comparing the efficiency and cost-effectiveness of manual versus mechanical harvesting methods. Data indicates that hand-harvested cotton yielded a marginally higher ginning outturn (41.4%) than machine-harvested crops (39%). This suggests that while manual picking offers a slight advantage in fiber recovery, the discrepancy between the two methods remains minimal.

Columbus (1988) conducted study on a spindle-type cotton picker was modified to enable selective harvesting of bolls from several sections of the plant, including the upper and lower sections, either separately or in combination. Post-harvest processing was conducted via micro-ginning, followed by a rigorous assessment of the resulting fiber quality parameters. The results indicated noticeable variations in fibre characteristics depending on whether the cotton was picked from the top, bottom, or from the entire plant.

Mayfield (1989) reported that spindle pickers, when properly managed, can harvest more than 95% of the cotton efficiently. They highlighted several critical concerns such as field losses and deterioration in fibre quality like spindle wrapping and increased trash content are often the result of poor machine operation and inadequate maintenance rather than limitations of the equipment itself. He also

emphasized that cotton should be harvested under dry conditions to achieve better results. Furthermore, proper preparation of both the crop and the harvesting machinery before the picking operation is essential to ensure high efficiency and maintain fibre quality.

Asota (1996) examined the performance of a manually operated cotton picker developed with a continuous chain mechanism fitted with picking fingers. These fingers were designed to engage with the cotton bolls and gently detach the fibre. The results indicated that the machine was capable of harvesting approximately 90-95% of the available cotton, out of which nearly 98% was successfully collected in the storage bag. Only a small proportion, about 2%, was lost to the ground and this loss was found to be statistically insignificant ($p < 0.05$) when compared with overall machine harvesting losses. Additionally, it was discovered that the quantity of contaminants in cotton harvested mechanically was similar to that of cotton harvested by hand, with just a slight variation of about 17%.

Chaudhry (1997) indicated that about one-third of the cotton produced worldwide was harvested using mechanical methods at that time. According to the study, machine-based cotton harvesting has been fully accepted by nations like Australia, Israel and the United States, despite the fact that the associated operating expenses varied greatly across them. Two primary types of mechanical harvesters are commonly used: pickers and strippers. Cotton pickers are designed for selective harvesting, removing only mature and open bolls while allowing immature bolls to remain on the plant for later development. These machines typically use either tapered barbed spindles or straight spindles to extract the cotton fibres. In contrast, strippers operate in a non-selective manner by removing both opened and unopened bolls in a single pass. Modern strippers function by guiding plants between inclined rotating rollers or between a roller and a stripping bar and they are generally categorized as finger-type or brush (roll-type) strippers. Mechanical stripper harvesters demonstrate optimal efficiency in environments characterized by determinate cotton varieties. These cultivars typically exhibit a compact growth habit and shorter fiber lengths, which facilitate more streamlined separation and cleaning during post-harvest processing.

Bauer (1998) investigated the variation in cotton yield in relation to different harvesting approaches. For this purpose, the experimental site was partitioned into distinct treatment plots of about 1341 cm (44 ft) length and two rows from each section were harvested using a spindle-type mechanical picker. In addition, smaller segments

measuring around 182 cm (6 ft) were manually harvested from three different soil units within each plot to obtain comparative data. The analysis revealed that there was no significant difference in yield variability between the mechanically harvested samples and those collected by hand.

Khalilian *et al*. (1999) reported that cotton harvest losses can increase significantly up to about 20% when picking is delayed after defoliation or when harvesting equipment is not properly adjusted, with variations depending on cotton type and field conditions. Their study focused on evaluating the performance of a boll saver attachment under field conditions over three consecutive harvesting seasons. During the trials, observations were made on stalk losses, ground losses, lint turnout percentage and overall yield for each experimental plot. The empirical data indicates that the use of the boll saver attachment effectively reduced both ground losses and total harvesting losses across all tested cotton varieties. The quantity of lint saved because of the attachment ranged from 27 to 59 kg/ha. Additionally, the trash content in the harvested cotton remained almost unchanged whether the attachment was used or not. It was also noted that the attachment did not significantly influence lint yield within the same cotton variety.

Prasad and Majumdar (1999) examined the prospective need for mechanized cotton harvesting in India, emphasizing that traditional hand picking is both labor-intensive and time-consuming, leading to considerable physical strain on workers. Their research identified two primary types of machines used for cotton harvesting: pickers and strippers. Mechanical pickers are designed to extract cotton seed from opened bolls, allowing immature bolls to remain on the plant for subsequent harvesting cycles. In contrast, strippers remove both opened and unopened bolls simultaneously, making them less selective in operation. The study also noted that spindle-type pickers are generally suited for wider row spacing, typically ranging between 97 and 102 cm, whereas strippers are more compatible with narrower row configurations. Comparative evaluations of these harvesting methods revealed that brush-type strippers tend to collect a higher proportion of foreign matter (trash) compared to spindle pickers. Additionally, cotton harvested using brush strippers was observed to have relatively higher moisture content than that obtained through spindle-based picking systems.

Sandhar (1999) assessed the performance of cotton harvesting machines under Punjab conditions, focusing on both picker and stripper types. The findings indicated that the effectiveness of these machines is highly dependent on the characteristics of

the cotton variety used. In general, both picker and stripper machines perform better with compact plant types, such as sympodial or semi-sympodial varieties and where boll opening occurs in a more synchronized manner. However, under the prevailing field conditions and commonly grown varieties in Punjab, the picker-type machines did not achieve satisfactory performance. This limitation was mainly attributed to the mismatch between machine requirements and the existing crop characteristics.

Nelson *et al.* (2001) examined the economics of different cotton harvesting systems by comparing various configurations of pickers and strippers across a range of farm sizes. Their analysis included 2, 4, 6 and 8-row stripper units, as well as picker systems with 2, 4 and 6-rows, with and without the use of bur extractors. The findings indicated that, in the case of stripper-based systems without bur extractors, smaller farms (below approximately 486 ha) achieved the lowest harvesting costs with four-row strippers. As farm size increased, six-row strippers became more cost-effective for areas roughly between 526 and 607 ha, while eight-row strippers were better suited for farms exceeding about 648 ha. For picker-based systems, a similar trend was observed. Two-row pickers were found to be the most economical option for smaller farms up to around 243 ha. Medium-sized farms, ranging from about 283 to 486 ha, benefited more from four-row picker systems, whereas six-row pickers became the optimal choice for larger holdings of approximately 526 ha or more. Overall, the study highlights that the selection of harvesting equipment should be closely aligned with farm size to achieve cost efficiency in cotton production.

Bulent (2003) examined how different design parameters influence the performance of a simple cotton picking machine across various cotton varieties. The key parameters considered in the study included vacuum pressure, suction velocity and the amount of force required to separate the cotton locks from the bolls. The analysis revealed that these parameters varied significantly with the type of cotton variety, particularly due to differences in lock detachment (break-off) force. It was observed that the Nazilli 84 variety required comparatively less force to separate the cotton locks from the bolls than some newly developed varieties. Despite these variations, the study concluded that a suction velocity of around 2 m/s combined with a vacuum pressure of approximately –5 kPa was adequate for effective detachment of cotton locks across the tested varieties. These results emphasize the significance of optimizing machine design parameters according to crop characteristics for efficient cotton harvesting.

Selvan *et al.* (2004) focused on optimizing the operational parameters of a pneumatic cotton picker. The researchers examined key design variables such as the diameter of the pick-up pipe, type and height of the filter, size of the collection drum and the speed of the aspirator. Based on their analysis, an optimal configuration was identified, which included a pick-up pipe diameter of 25 mm, a nylon mesh filter and a collection drum with a filter height of 300 mm. The aspirator performed most effectively at a speed of 3500 rpm. The performance of the machine varied across different stages of picking. Operational data indicated a marginal increase in field capacity from the initial harvest to the final stage. While mechanical efficiency followed a positive trajectory as the crop reached full maturity, this improvement was coupled with a proportional rise in non-lint content (trash), which peaked during the third picking. The energy requirement of the pneumatic picker was estimated to be around 1910.90 ± 68.28 kcal per day. In terms of operational comfort, the sound pressure level generated by the machine was measured at approximately 86.22 dB, which may have implications for operator safety and ergonomics.

Kitsopanidis *et al.* (2005) examined the optimal replacement period for cotton pickers under both technical and economic conditions in Greece. The analysis was based on field data collected from 62 machines operating in the central region of the country. To determine the most suitable replacement time, five different evaluation approaches were employed. The first three methods suggested that replacement should occur when the cumulative annual depreciation cost becomes equal to the repair and maintenance expenses, or when the total hourly operating cost reaches its lowest level. The fourth method identified the optimal point as the year in which the average total cost per hour of operation or per hectare harvested is minimized. The fifth approach, however, focused on profitability, indicating that replacement should take place when the standardized net income generated by the machine is at its maximum. The findings of the study revealed that the most appropriate time to replace a cotton picker falls between the 14th and 15th year of its operational life. This corresponds to an accumulated usage of approximately 4,500 to 5,000 working hours and a coverage of about 1,450 to 1,550 hectares.

Rangasamy *et al.* (2006) investigated the performance characteristics and design parameters of a pneumatic knapsack cotton picker. Key machine variables such as pickup pipe diameter, filter type and height, collection drum capacity and aspirator speed were optimized using statistical techniques. The study identified that a

configuration consisting of a 25 mm diameter pickup pipe, a nylon mesh filter with a height of 225 mm, a 25-litre collection drum and an aspirator operating at 5,500 rpm produced the most effective suction pressure. The operational performance of the machine varied across different picking stages and cotton varieties. Field capacity during the first picking stage was recorded at 4.93 kg/h, which slightly increased to 5.07 kg/h during the third picking. Among the tested varieties, P4 showed the highest field capacity (5.20 ± 0.03 kg/h), whereas the lowest was observed in the Sumangala variety (4.85 ± 0.06 kg/h). Similarly, picking efficiency improved with successive pickings, increasing from 96.35% in the first picking to 97.48% in the third. The MCU12 variety exhibited the highest efficiency (97.83 ± 0.15%), while the Anjali variety recorded the lowest (96.45 ± 0.20%). However, it was also noted that the trash content in machine-picked cotton was highest (13.97%) during the third picking stage.

Selvan *et al.* (2007) categorized modern cotton strippers based on two main operating mechanisms: the finger-type system and the roller-type system. In the roller mechanism, cotton plants pass either between two inclined rotating rollers or between a roller and a stationary stripping bar, which facilitates the removal of bolls. These machines have been found to perform more effectively in regions where cotton plants are relatively short and produce fibres that are firm, compact and easier to separate and clean. Their study further highlighted that, when factors such as harvesting cost, breakeven period, payback duration and savings in time, labour and energy are taken into account, the use of mechanical cotton pickers offers significant potential and economic advantages over conventional methods.

Tajuddin (2008) designed and evaluated a pneumatic cotton picker powered by a 3.3 kW petrol-start, kerosene-run engine operating at 3000 rpm, which was connected to a centrifugal aspirator. The machine generated an air suction force of approximately 334 g and achieved a picking capacity of about 3 kg/h. However, the harvested cotton contained a noticeable amount of trash, necessitating additional cleaning. The study also indicated that the machine would become economically viable only when a break-even picking capacity of around 7.2 kg/h is attained.

Mygdakos (2009) examined the key factors influencing the performance of a cotton picker operated by a growers' association, along with their impact on harvested area and overall harvesting cost. In this study, a machine with defined technical specifications was analyzed and both stochastic and deterministic models were developed to represent the harvesting system. These models were used to simulate field

operations and estimate the area covered as well as the associated costs, based on average weather conditions and other relevant parameters. Additionally, sensitivity analysis was carried out to understand how variations in input variables and system parameters affect machine performance. The findings indicated that weather-related factors, particularly rainfall and precipitation levels, had the most significant influence on picker efficiency. Other contributing factors included crop moisture content, duration of the harvesting period, machine reliability and the time required for movement between fields.

Kathiria (2011) a knapsack-type powered cotton picker was designed and evaluated under field conditions. The performance of the machine was tested using different picking spout diameters (32, 40 and 50 mm) along with varying aspirator speeds of 3000, 4000 and 5000 rpm. The results indicated that the force required for picking cotton bolls varied between 2.03 and 2.55 N. The mechanical harvester demonstrated high operational efficiency, maintaining a picking effectiveness between 94.92% and 96.46%. During field tests, the machine consumed fuel at a rate of 0.28 l/h while yielding a throughput of approximately 6.06 kg/h. Although the trash content ranged from 5.50% to 7.50%, the system proved financially viable with an operational expenditure of 5.07 ₹/kg. Financial modeling suggests a rapid return on investment, evidenced by a 0.47-year payback period and a break-even threshold of 392.42 kg/year.

Sharma *et al.* (2011a) developed a cotton-harvesting assistance tool was introduced to optimize the collection of open bolls. The mechanism utilized a pneumatic suction system, with the operational pressure calibrated based on the critical threshold of force required to successfully detach the cotton fibers from the plant. This force was calculated to be approximately 3.6 N for a picker nozzle with a diameter of 25 mm. A cyclone separator was incorporated into the design to facilitate the collection of picked cotton. Based on an airflow rate of 0.076 m^3/s, the dimensions of the cyclone inlet duct were determined by considering an air velocity of 15 m/s at the exit, along with appropriate inlet and outlet velocity conditions. To enhance the picking performance, an electromagnetic mechanism was integrated and the current required to operate the electromagnetic valve was estimated at 4.26 A. The system's design was validated through detailed modeling of pressure and frictional losses, totaling 8.216 mm Hg. Following the fabrication of a physical prototype, performance trials were conducted to assess its viability. Key metrics recorded during these tests included total power requirements and fuel efficiency during standard operation.

Sharma *et al*. (2011b) conducted a performance evaluation of a pneumatic cotton picking assistant, using different combinations of picker end diameters (20, 25, 32 and 40 mm) and suction pressures ranging from 25 to 50 mm Hg. Investigation into pneumatic harvesting parameters revealed that picker end dimensions and suction intensity significantly dictate performance outcomes. Empirical results demonstrated that a 25 mm picker diameter combined with 45 mm Hg suction pressure optimized both picking efficiency (96.3%) and total output capacity (6.25 kg/h). Conversely, while higher pressures boosted productivity, a reduced diameter of 20 mm at 30 mm Hg was more effective for minimizing trash content, achieving a low of 0.65%. These findings suggest a trade-off between throughput volume and harvest purity. Studies on picker nozzle parameters (25 mm diameter) reveal that suction pressure significantly influences cotton quality and collection rates. While higher pressures (50 mm Hg) optimize throughput, lower pressures (35 mm Hg) are more effective for minimizing debris. Specifically, trials recorded minimum trash levels of 4.39% to 5.70% at 35 mm Hg, sustaining an average output of approximately 4.1 kg/h and an efficiency exceeding 92%.

Selvan *et al.* (2012) designed a pneumatic harvesting system tailored to the physical requirements of female laborers. Their research prioritized the development of a cotton picker that accommodates the specific morphological traits of Indian cotton cultivars while ensuring operational ease for women in the field. The machine was designed as a four-wheeled, push-type trolley unit. Key operational parameters such as pick-up pipe diameter, type and height of the filter, capacity of the collection chamber and aspirator speed were systematically optimized using a build-and-test approach. The influence of these parameters on suction pressure, which governs the picking force, was carefully analyzed. Statistical optimization determined that peak performance is achieved through a specific hardware synergy: a 50 mm diameter intake pipe coupled with a 300 mm nylon mesh filtration unit. Furthermore, the system necessitates a 50-liter reservoir and a consistent aspirator velocity of 3500 rpm to maintain efficiency. Economic evaluation of the mechanical harvester revealed a significant improvement over manual methods, with an operational cost of 11.10 ₹/kg. The transition to mechanization yielded substantial efficiencies, specifically reducing labor time by 67.5%, energy consumption by 66.6% and overall harvesting costs by 15.8%. From an investment perspective, the technology demonstrated strong viability with a calculated payback period of 2.3 years and a break-even threshold of 1147 kg/year.

Manes *et al.* (2012) evaluated the efficacy of a portable, battery-powered cotton harvester against traditional manual harvesting methods. By employing two distinct operators across three cotton cultivars, the researchers established a performance baseline for mechanized handheld alternatives to labor-intensive hand picking. The device is manually handled and powered by a lightweight 12 V battery. It consists of a pair of moving chains fitted with small, sharp-edged teeth mounted on sprockets. During operation, the cotton fibres become entangled in the chains and are subsequently conveyed into a collection bag. The machine's picking capacity ranged between 17.0-22.6 kg/day for Bt and American cotton varieties. Performance evaluations across diverse cotton cultivars revealed significant fluctuations in mechanical picking efficiency, which spanned a range of 68% to 91%. Concurrently, the qualitative analysis of the harvested yield indicated variable impurity levels, with trash content fluctuating between 1.8% and 6.1%.

Verma (2013) evaluated the performance of a knapsack-type cotton picker under controlled laboratory conditions. Previous studies have evaluated mechanical performance by analyzing critical operational metrics, including fuel economy and harvesting efficiency. Furthermore, researchers monitored pneumatic variables such as suction pressure at the nozzle tip and internal drum pressure, alongside qualitative indicators like total trash content. These parameters were analyzed at different operational settings, including aspirator speeds of 2500, 3500, 4500 and 5500 rpm, pick-up pipe diameters of 20, 25 and 30 mm and aspirator bowl openings of 50%, 75% and 100%. The results indicated that fuel consumption varied between 0.72 and 1.31 l/h, while picking efficiency ranged from 94.42% to 96.85%. Trash content was observed between 8.16% and 11.33%. The suction pressure at the pipe tip ranged from 0.035 to 0.076 kg/cm^2, whereas the pressure inside the collection drum varied from 0.023 to 0.047 kg/cm^2. In field assessments, the machine's performance was analyzed utilizing a pickup pipe diameter of 25 mm and a fully extended bowl opening (100%), while maintaining a constant aspirator velocity of 5500 rpm. Under these optimized conditions, the average fuel consumption was recorded as 1.295 l/h, with a picking efficiency of 96.47% and trash content of 10.22%. The output capacity of the machine was found to be 4.95 kg/h for both the first and second pickings. Economic analysis revealed that the cost of operation was 10.88 ₹/kg of cotton picked. In comparison to traditional manual harvesting, the use of the knapsack cotton picker resulted in a time saving of approximately 69.85%. Additionally, the break-even point was estimated at

278.46 kg/year, with a payback period of about 0.55 years, indicating the economic feasibility of the machine.

Sharanbasava (2021) focused on the development and evaluation of a tractor-operated pneumatic cotton picker to address labour shortages and high harvesting costs in cotton production. The machine, consisting of components such as a blower, suction chamber, pick-up pipe and storage unit, was designed for single-operator use. Biological and physical properties of cotton (BGDS-1063) were analysed to aid in design, where average plant height (88.57 cm), number of fully opened bolls (20.11) and boll weight (5.72 g) were recorded. Laboratory optimization revealed an optimum suction pressure of 0.10876 kg/cm^2 at 7500 rpm with a 40 mm pipe diameter. Field evaluation showed a field capacity of 0.125 ha/h, picking efficiency of 70.45% and fuel consumption of 6 l/h. The machine significantly outperformed manual picking, achieving 191 kg/h compared to 2.25 kg/h, while reducing operation time drastically. Economic analysis indicated a total operating cost of 881.6 ₹/h, with a benefit-cost ratio of 2.75 and payback period of 1.27 years. The study concluded that the developed picker is cost-effective, reduces labour dependency and is suitable for small and marginal farmers.

Dayanand (2021) introduced a pneumatic-based suction harvester tailored for the needs of marginal cotton growers. This innovation serves as a strategic response to labor deficits and the high financial burden of traditional harvesting methods. The study compared machine picking with manual harvesting under different plant spacings and suction pipe lengths using Bt cotton varieties. Results showed that the machine significantly improved effective field capacity (up to 0.0096 ha/h) and output capacity (about 19.85-20.65 kg/h) compared to manual picking (0.00140-0.00148 ha/h and 2.84-3.43 kg/h). The cost of picking was reduced (₹13,953-₹16,325/ha) compared to manual methods (₹22,856-₹23,176/ha), with savings of 32.80% in cost, 79.68% in time and 71.95% in energy. Although manual picking showed slightly higher picking efficiency (~89.9%), the machine offered better overall performance with lower physiological cost and higher daily capacity (126 kg/day vs. 25.6 kg/day). The break-even point and payback period of the machine were 3379.88 kg/year and 4.44 years, respectively.

Khanpara (2022) focused on the development and evaluation of a knapsack power-driven cotton picker to overcome the limitations of manual harvesting in India. The researcher designed the machine by considering agronomical, engineering and ergonomic requirements and used a 0.9 kW engine operating at 5500 rpm. For optimal

performance, a picking spout diameter of 40 mm and an aspirator speed of 5000 rpm were selected. The outcomes showed that the developed cotton picker achieved a picking capacity of 7.62 kg/h compared to 3.72 kg/h in manual picking, nearly doubling productivity. The picking efficiency of the machine (95.79%) was found to be comparable with manual picking (96.93%). However, trash content was higher in machine picking (8.13%) than manual method (3.59%). Fuel consumption of the machine was recorded as 0.275 l/h. The study further revealed that the use of the knapsack cotton picker reduced time and cost of harvesting by 51.44% and 14.86%, respectively. Although energy requirement was higher (about 2.79 times of manual method), overall net realization increased by 3.27%. The researcher concluded that the developed cotton picker is an effective and economical alternative to manual picking with satisfactory performance.

12.3. Economics of cotton picker

Selvan *et al.* (2007) designed a knapsack-type cotton picker and evaluated its economic performance with the aim of reducing the drudgery associated with manual harvesting while also improving the quality of picked seed cotton. The economic analysis of the machine was carried out following the RNAM test code and procedures for harvesters to assess its feasibility and cost-effectiveness. The initial cost of the developed machine was approximately ₹5000 and the operational cost of cotton picking was estimated at ₹4.55 per kilogram when operated using kerosene as fuel. In comparison to conventional hand picking, the use of this machine resulted in significant savings in cost, time and energy, amounting to 9.00%, 75.00% and 68.23%, respectively. The breakeven point of the machine was calculated to be 394.46 kg per year, with a payback period of about 0.81 years, indicating its economic viability for small-scale use.

Selvan *et al.* (2011) evaluated the economic feasibility of a walking-type cotton picker designed to be operated by two female workers. The operational cost per kilogram of seed cotton was estimated using the methodology prescribed under the RNAM test code. This cost was then compared with the traditional hand-picking method to assess savings in terms of cost, time and labour energy. The analysis revealed that the machine had a payback period of approximately 1.16 years, with a break-even output of about 940 kg/year. The initial purchase cost of the machine was ₹40,000 and the picking cost was calculated to be 11.33 ₹/kg when operated using kerosene as fuel. Overall, the results demonstrated considerable advantages of the mechanical picker,

including reductions of 24.5% in cost, 67.5% in time and 66.6% in labour energy compared to manual cotton picking.

13. Materials and Methods

13.1 Location of experiment

The experiment will be carried out at the Department of Farm Machinery and Power Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh.

13.2 Year of experiment: 2027-28.

13.3 Plan of work

The objectives shall be achieved through following plan of work:

1. Problem identification and project formulation.
2. Collection of review of literature and information regarding existing harvesting method and techniques.
3. Determination of the physical properties of cotton.
4. Design considerations.
5. Conceptual design/drawing of the proposed pneumatic cotton picker.
6. Development of tractor operated pneumatic selective cotton picker.
7. Layout of experimental plot.
8. The developed pneumatic selective cotton picker will be compared with the traditional/existing methods for its economics and suitability.
9. Thesis writing.

13.4 Design considerations

1. It should be simple in fabrication and easy to manufacture using locally available materials.
2. All parts can be easily assembled and dismantled for inspection and repair.
3. It should have suitable filter to restrict the entry of cotton inside the aspirator.
4. It should be safe to operate.

13.5 Conceptual design of machine

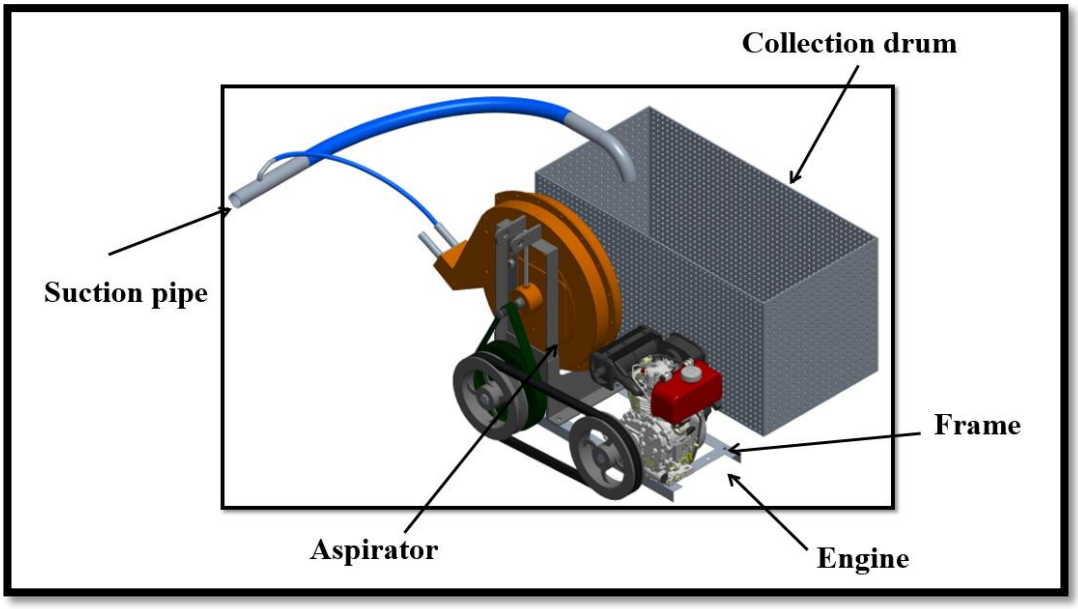

Figure 1. Isometric view

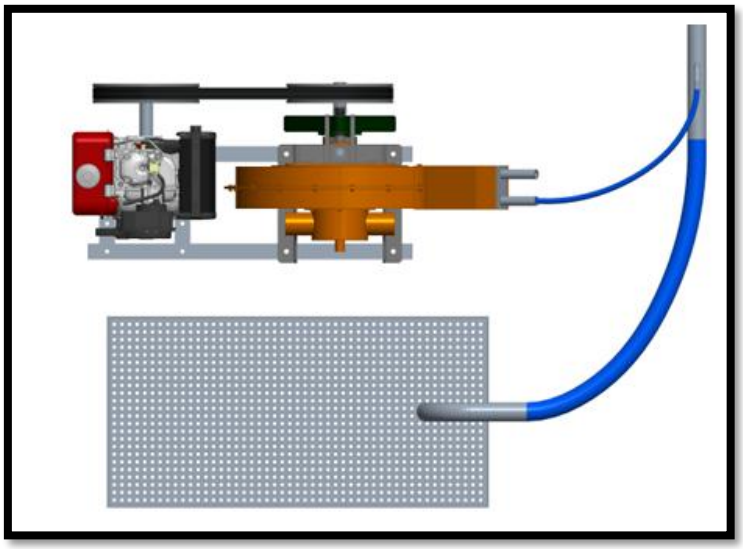

Figure 2. Top view

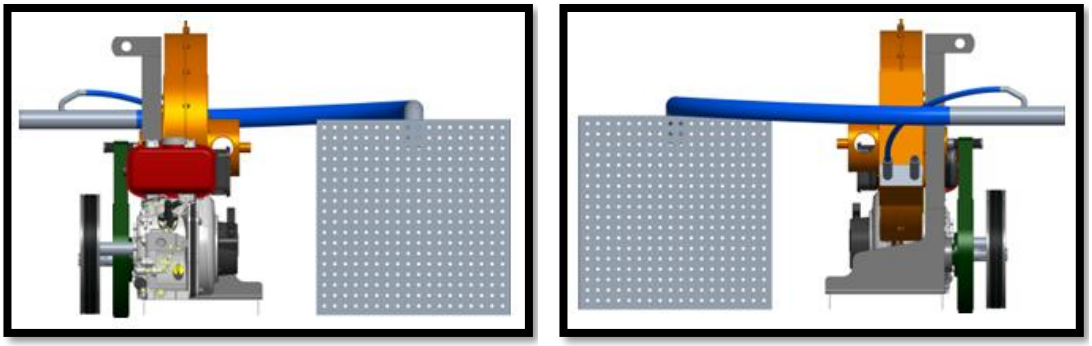

Figure 3. Side view

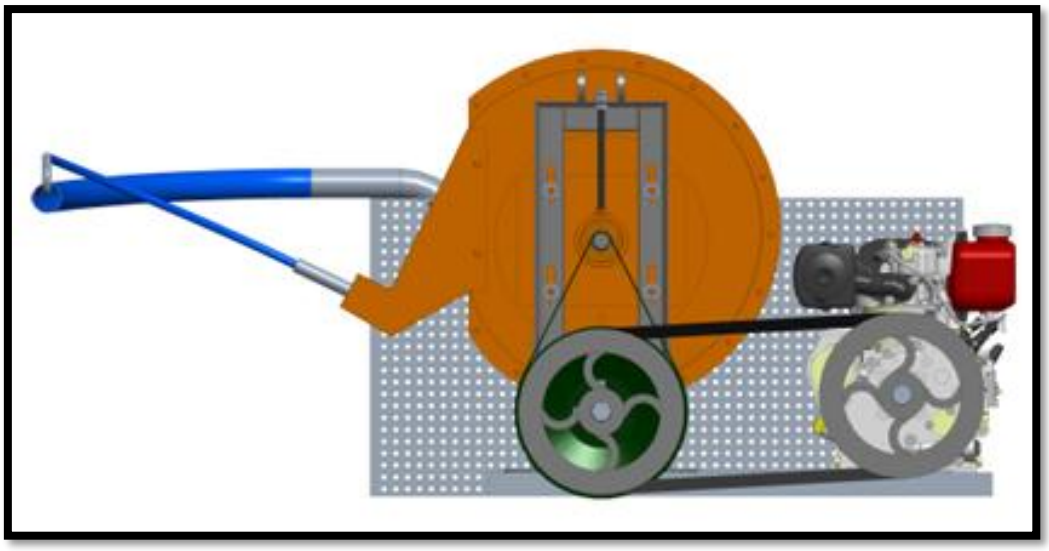

Figure 4. Front view

13.6 Main components of machine

13.6.1 Collection drum

A polypropylene drum will be used as a collection drum. The bottom of the collection drum will be attached to the impeller's eye and it will be fixed to the frame.

13.6.2 Suction pipe

The suction hose pipe will be made of flexible PVC. The suction pipe's two ends will be connected to the pick-up pipe and the collection drum, respectively.

13.6.3 Pick-up pipe

One PVC pick-up pipe will be connected to the suction pipe.

13.6.4 Aspirator

It will be used to suck the picked cotton through the suction pipe and help to collect the cotton bolls in the collection drum.

13.6.5 Venturi mechanism

A venturi mechanism will be employed to maintain a constant pressure throughout the system, ensuring smooth and efficient pneumatic cotton picking.

13.6.6 Filter

A suitable filter screen will be required to prevent cotton from entering into the aspirator and to allow only air to pass into the aspirator.

13.6.7 Frame

The whole assembly of pneumatic type cotton picker will be mounted on iron frame. It will be made from light weight iron hollow pipe.

13.7 Performance evaluation of the machine

Table 2. Details of experimental field

Sr. No.	Variables	Parameters	Levels
1.	Independent Parameters	Speed of aspirator (rpm)	S_1 = 5000 S_2 = 6000 S_3 = 7000
		Diameter of picking spout (mm)	D_1 = 30 D_2 = 40 D_3 = 50
2.	Dependent Parameters	Air velocity, m/s Sucking pressure, N/mm^2 Picking capacity, kg/h Picking efficiency, %	

***Above level will be subjected to change depending upon preliminary trials of machine**

13.8. Experimental details

- ✓ Statistical design: large plot technique
- ✓ No. of treatment combination: 3 × 3 = 9
- ✓ No. of replications: 3

Table 3. Details of various treatment combinations

Sr. No.	Name of Treatment	Combination
1.	**Treatment 1** (T_1)	D_1S_1
2.	**Treatment 2** (T_2)	D_1S_2
3.	**Treatment 3** (T_3)	D_1S_3
4.	**Treatment 4** (T_4)	D_2S_1
5.	**Treatment 5** (T_5)	D_2S_2
6.	**Treatment 6** (T_6)	D_2S_3
7.	**Treatment 7** (T_7)	D_3S_1
8.	**Treatment 8** (T_8)	D_3S_2
9.	**Treatment 9** (T_9)	D_3S_3

13.9 Detail of experimental variables

Cotton sample will be taken to determine the following properties and other necessary parameters are enlisted in the following Table 4.

Table 4. Details of experimental variables

Sr. No.	Parameters
A.	**Physical properties of cotton**
1.	Size (Equivalent diameter) of open boll
2.	Volume
3.	Density

B.	**Machine Performance Parameters**
1.	Air velocity
2.	Sucking pressure
3.	Picking capacity
4.	Picking efficiency
5.	Weight of picked cotton per batch
6.	Harvesting losses
7.	Time losses
8.	Field efficiency (%)
9.	Cost Economics

13.10 Physical properties of cotton bolls

13.10.1 Size (Equivalent diameter) of open boll

The size of a cotton boll represents its physical dimensions and plays an important role in analysis. To measure this accurately, a digital Vernier caliper with a least count of 0.01 mm will be used. For the study, ten cotton bolls will be selected randomly so that the observations properly represent the sample. Each boll will be measured in three perpendicular directions length, width and thickness to capture its overall shape. All readings will be recorded in millimeters (mm). Based on these measurements, the equivalent size of the open cotton boll will be computed using a standard formula (Mohsenin, 1980).

$$\text{Equivalent diameter} = (lbt)^{1/3} \quad \text{… Eq. 1}$$

Where,

l = maximum perpendicular dimension

b = intermediate perpendicular dimension

t = minimum perpendicular dimension

13.10.2 Volume

To quantify the volume of a cotton boll, a cylindrical container will be used. The boll will be carefully placed and slightly pressed inside the cylinder so that it fits properly and the height it occupies will then be noted. Using this measured height, spherical object is derived analytically from the primary dimensions of the corresponding cylinder. This method of estimation is adopted as outlined (Mohsenin, 1980).

$$\text{Volume} = \pi r^2 h \quad \text{… Eq. 2}$$

Where,

r = radius of cylindrical box, mm

h = height of cotton boll pressed into the cylindrical box, mm

13.10.3 Density

The density of a cotton boll will be calculated as the ratio of its mass to its volume. The unit of measurement will be gm/mm^3 (Mohsenin, 1980).

13.11 Machine Performance Parameters

13.11.1 Air velocity

The air velocity at the inlet of the picker, corresponding to different operating speeds, will be recorded using a handheld digital air anemometer.

13.11.2 Sucking pressure

A U-tube manometer will be used to measure the suction pressure at the picking spout's tip under various aspirator speed and spout diameter combinations.

13.11.3 Picking capacity

The picking capacity, which can be computed using the following formula, is the amount of cotton seed that the machine can collect in a specific amount of time (Rangasamy *et al*., 2006).

$$C_p = W_p / t \quad \text{… Eq. 3}$$

Where,

C_p = Picking capacity, kg/h

W_p = Weight of cotton picked, kg

t = Time taken, h

13.11.4 Picking efficiency

The picking refers to the proportion of clean seed cotton successfully collected in relation to the total potential yield, which also accounts for losses occurring before and during harvesting. The following formula can be used to compute it: (Rangasamy *et al*., 2006).

$$n_p = W_p / W_t \times 100 \quad \text{… Eq. 4}$$

Where,

n_p = Picking efficiency, %

W_p = Weight of cotton picked from plant, kg

W_t = Weight of total cotton on plant, kg

13.11.5 Weight of picked cotton per batch

The quantity of cotton that the machine gathers in a single continuous operation prior to the storage sack being emptied is referred to as a batch. The cotton gathered in each cycle will be weighed in kilograms prior to unloading. The total number of such batches completed within an hour will be estimated by considering the effective working time of the machine along with the time required for unloading the filled sack.

13.11.6 Harvesting losses

The harvesting losses refer to the portion of seed cotton that remains on the plant even after the machine has completed its operation. The cotton that is left behind is usually collected later through manual picking. The extent of these losses can be estimated using the following formula:

$$\text{Harvesting losses (\%)} = W_c / W_d \times 100 \quad \text{… Eq. 5}$$

Where,

W_c = Weight of seed cotton left on the plant after picking, kg

W_d = Weight of total yield, kg

13.11.7 Time loss

The time duration involved in unloading the collected cotton sacks will be noted carefully. Based on these observations, the overall time lost during the unloading process will be estimated. In addition, the time spent on refueling the machine will also be measured, thus it is essential for precisely determining the machine's effective field capacity.

13.11.8 Field efficiency

The percentage of actual working time that a machine operates in the field at its intended operating speed and effective working breadth is known as field efficiency.

$$\text{Field efficiency } (\%) = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100 \quad \ldots \text{Eq. 6}$$

13.11.9 Cost of operation

To evaluate the economic viability of the machinery, operational costs will be determined through a dual-metric approach, calculating expenses on both a per-hour and per-hectare basis. This analysis differentiates between fixed and variable costs, utilizing the straight-line depreciation technique in strict accordance with the standardized protocols established by IS: 9164-1979. This approach considers that the machine loses its value uniformly over its useful life, with an equal amount of depreciation occurring each year.

14. Statistical Analysis

The experimental data will be statistically analyzed using a Factorial Completely Randomized Design (FCRD) to evaluate the influence of different treatments on the observed parameters. The analysis will be carried out following the standard methodology outlined by Panse and Sukhatme (1957).

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